TRANSBOUNDARY VIRTUAL WATER AND WATER FOOTPRINT FOR SOME CROPS IN EGYPT

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ABSTRACT

Water footprint and virtual water flow analyses were conducted for rice, wheat, maize, and sugarcane. From results, the water footprint of Egyptian rice is 1593 m^3/ton which is 0% green, 82% blue, and 18% grey water footprint. It is advised to decrease the planted rice area to 0.95 MFed/year. Rice is preferred to import. However, the water footprint of wheat is 1932 m^3/ton which is 2.7% green, 67.9% blue, and 29.4% grey water footprint. It is advised to increase the planted wheat area to 36.7MFed/year. Wheat is preferred to cover nation consumption and not preferred to import. Not only that but also, the water footprint of Egyptian maize is 2079.8 m^3/ton which is 1% green, 60.6% blue, and 38.4% grey water footprint. It is advised to export maize to get high income. The water footprint of sugarcane is 349.8 m^3/ton which is 0.83% green, 89.14% blue, and 10% grey water footprint. It is advised not to import sugarcane due to the imported is lower than the exported economic water productivity.

Key words: *water footprint, green water footprint, blue water footprint, virtual water, economic water productivity, energetic water productivity.*

INTRODUCTION

Water is the source of life on the earth. Difficult to purify, expensive to transport and impossible to substitute, water is essential to: food production, economic development, and to life itself. In the last century, there is a large global water shortage not only because of the physical water scarcity, but also because of poor water management.

By linking a large range of sectors and issues, virtual water and water footprint analyses provide an appropriate framework to find potential solutions and contribute to a better management of water resources (**Aldaya and Llamas, 2008**). Moreover it is a must to manipulate water use strategy.

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The concept of water footprint helps to improve policy implications on agriculture geographical dispersion, consumption behavior changes, trade structure adjustment and water use efficiency improvement.

The water footprint is a multidimensional indicator, showing water consumption volumes by source and polluted volumes by type of pollution; all components of a total water footprint are specified geographically and temporally **(Hoekstra *et al.*, 2011).**

Detailed national water footprint studies have been conducted for European countries **(Van Oel *et al.*, 2009)** and countries outside Europe, **(Bulsink *et al.*, 2010; Liu and Savenije, 2008; Verma *et al.*, 2009).**

In this study, Egypt will be taken as study case. However Egypt is the gift of the Nile, there is shortage in water level because of increasing population and non efficient water use. So a general overview of the virtual water and water footprint will be considered.

The objectives of this study are to quantify the volumes of all virtual water trade flows over the period 2008-2012 in Egypt for some crops from hydrological and economic perspectives and put the virtual water trade balances of these crops within the context of national water needs and water availability.

METHODOLOGY

The virtual water and water footprint are calculated using the methodology developed by **Hoekstra and Hung (2002; 2005)** and **Chapagain and Hoekstra (2003; 2004).**

Crop water requirement estimation:

For calculating green and blue crop water requirement, evapotranspiration must be estimated. CROPWAT.8 Model was used to estimate green and blue evapotranspiration. There are two different ways to do this: using the crop water requirement option (assuming optimal conditions) or the irrigation schedule option (including the possibility to specify actual irrigation supply in time). The latter option was applied in this study. A comprehensive manual for the practical use of the program is available online **(FAO, 2010b)**. The green and blue components in crop water use (CWU, m^3/ha) were calculated by accumulation of daily evapotranspiration (ET, mm/day) over the complete growing period **(Hoekstra *et al.*, 2011)** as indicated in equations (1) and (2) as follows:

$$CWU_{green}(m^3/ha) = 10\sum_{d=1}^{1gp} ET_{green} \quad \dots\dots (1)$$

$$CWU_{blue}(m^3/ha) = 10\sum_{d=1}^{1gp} ET_{blue} \quad \dots\dots (2)$$

Where

CWU = crop water requirements (either green or blue) in m^3/ha; and

ET =daily evapotranspiration (either green or blue) in mm.

The water footprint accounting

Water footprint includes three elements: consumptive use of rain water bounded in the soil (green water); consumptive use of water withdrawn from groundwater or surface water (blue water) and pollution of water (grey water), associates with the production of goods and services **(Cong and Stephen, 2009)**.

The green, blue, and grey water footprints are calculated as follows:

$$WF_{green}\ (m^3/ton) = \frac{CWU_{green}}{Y} \quad \dots\dots (3)$$

$$WF_{blue}\ (m^3/ton) = \frac{CWU_{blue}}{Y} \quad \dots\dots (4)$$

$$WF_{grey}(m^3/ton) = [\frac{\propto * Appl}{c_{max} - c_{nat}}]/Y \quad \dots\dots (5)$$

$$WF_{Tot}(m^3/ton) = WF_{green} + WF_{blue} + WF_{grey} \quad \dots\dots (6)$$

Where:

WF_{green}= The green water footprint in (m^3/ton);

WF_{blue} = The blue water footprint in (m^3/ton);

WF_{grey} = The grey water footprint in (m^3/ton);

WF_{Tot} = The total water footprint in (m^3/ton);

Appl = The chemical application rate to the field per hectare in (kg/ha);

α = Times the leaching-run-off fraction;

c_{max} = The maximum acceptable concentration in (kg/m^3);

c_{nat} = The natural concentration for the pollutant considered; Nitrogen in (kg/m^3); and

Y = The crop yield in (ton/ha).

Water footprint of a product

The water footprint of a product concludes the embedded and removed water to the crop during the production. The water footprint of a product is calculated as the total water footprint of non processing crop divided by the product fraction.

$$WF_{prod}\,(m^3/ton) = \frac{WF_{tot}}{F_{prod}} \quad \text{.......................................} (7)$$

Where:

WF_{prod} = The water footprint of a product in (m^3/ha); and

F_{prod} = The product fraction.

Product fractions can best be taken from the literature available for a specific production process **(FAO, 2003).**

Energetic water productivity (G.W.P)

Since the amount of energy produced by the unit mass of a crop fixed, the static indicator of the energy water productivity consumed or transported across different products for different countries. The energetic water productivity may be calculated as follows:

$$G.W.P = \frac{En_{output}}{WF_{Tot}} \quad \text{.......................................} (8)$$

Where:

G.W.P = Energetic water productivity in (Kcal/m^3); and

En_{output} = Energy output of the crop in (Kcal/ton) from **Pimentel and Hall (1984)** as follows:

Crops	Energy output (Kcal/ton)
Rice	3799233.182
Wheat	3313550.94
Maize	3500000
Sugarcane	379771.5

Economic water productivity (C.W.P)

The water economic productivity analysis can be very useful in order to identify possible water uses not justified in economic efficiency terms and achieve an efficient allocation of water resources **(Aldaya and Llamas, 2008).** Water economic productivity is calculated as follows:

$$C.W.P = \frac{G.W.P}{P_{EN}} \quad \text{.......................................} (9)$$

Where:

G.W.P= The energetic water productivity in (Kcal/m^3); and

P_{EN} = Energy price in ($/Kcal) from source **(World Bank, 2015).**

Virtual water trade flows and the national virtual water trade balance

Step 1: The volume of virtual water imported into Egypt (m^3/yr) is calculated as follows:

$$V.W.I = T_{crop} * WF_{import\ country} \quad \text{...(10)}$$

Where:

V.W.I = Virtual water imported (m^3/year);

T_{crop} = Crop trade (ton/year); and

$WF_{import\ country}$ = The virtual water content (m^3/ton).

Step 2: The volume of virtual water exported from Egypt (m^3/year) is calculated as:

$$V.W.X = T_{crop} * WF_{Egypt} \quad \text{...(11)}$$

Where:

V.W.X = Virtual water exported (m^3/year);

WF_{Egypt}= The export quantity by the average virtual water content of the crop (m^3/ton); and

T_{crop} = The amount of the crop exported (ton/year).

Step 3: The net virtual water import is calculated by subtracting the total virtual water import from the total virtual water export.

RESULTS AND DISCUSSION

The water footprint and virtual water flow analyses for rice, maize, wheat, and sugarcane crops are evaluated over the period (2008-2012). For these analyses, Egypt has been divided and analyzed into four areas (Upper, Middle, Lower Egypt and New areas).

Rice crop

1- **Cropping area**

The total planted area of rice in Egypt is about 1.47 M Fed. As a whole, more than 99% of the crop area is planted in Lower Egypt. As well as, Middle Egypt planted about 0.47% of total area. On the other side, New Areas planted about 0.26% of the total area. The total planted area of rice over the period (2008-2012) is shown in Table (1).

Table 1: The total planted area (Feddan) of rice over the period (2008-2012)

Egyptian Regions	Years					Average
	2008	2009	2010	2011	2012	
Lower	1729363	1368608	1378550	1404937	1399504	1456192
Middle	31941	484	101	285	1431	6848.4
NewAreas	8478	146	2091	3935	4282	3786.4
Total	1769782	1369238	1380742	1409157	1405217	1466827

1- Total water footprint for rice

The water footprint analysis establishes the amount of water required by specific crops and it differs considerably among crop type, yield and climate. Figure (1) provides an overview of the water footprint of rice (m^3/ton) in the different sections of the Egypt over different years. As shown in this figure, it is noteworthy that, New Areas containing larger amounts of water footprint (about 2246 m^3/ton) and Middle Egypt (about 1918 m^3/ton), however, Lower Egypt containing smaller amounts of water footprint (about 1435.9 m^3/ton) with regarded to **Chapagain and Hoekstra (2010)**. This result may be explained by the differences in yield, climate, and soil type for each region.

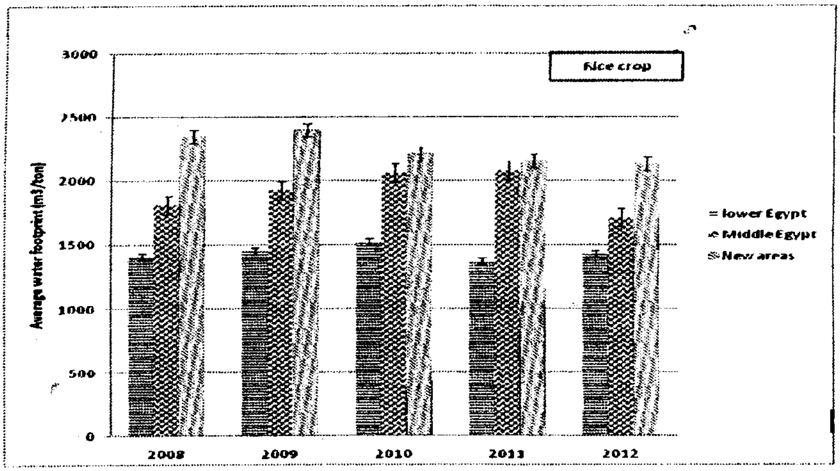

Fig. 1 Total water footprint of rice over the period (2008-2012)

The soil type in Lower Egypt is black and salty soil however Middle Egypt and New areas are medium black and sandy soil. In Lower Egypt, rice yield is about 8.9 ton/ha however yield in Middle Egypt and New Areas are 8.3 and 6.9 ton/ha respectively.

Table 2: Means, Standard deviation and Duncan's Multiple Range Test for total water footprint in different regions over the period (2008-2012).

Years	Egyptian regions					
	Lower		middle		New areas	
	Means	SD	Means	SD	Means	SD
2008	1409 N	224	1812 N	292	2344 *	514
2009	1452 N	261	1926 N*	43	2394 *	379
2010	1520 N	378	2063 N	-	2205 N	456
2011	1371 N	249	2080 *	-	2155 *	88
2012	1429 N	261	1712 N*	270	2199 *	-

* and N having the same letter in each column are not significantly at $p_r < 0.05$. The slash (-) means that there is not stander division for this region because there is one governorate planted rice there.

Table 3: Internal water footprint of produced rice (m^3/ton) for each region in Egypt over the period (2008-2012).

Region	Water footprint (m^3/ton)			Economic water productivity ($/ m^3)	Energetic water productivity (Kcal/ m^3)
	Green	Blue	Grey		
			2008		
lower Egypt	0.09	1120.25	288.25	3.0	2821.98
middle Egypt	0.07	1514.42	297.02	2.2	2137.30
New areas	0	1919.25	425.11	1.7	1660.61
			2009		
lower Egypt	0.17	1151.38	300.04	3.0	2693.85
middle Egypt	0	1621.61	303.97	2.2	1973.53
New areas	0	1987.45	407.01	1.8	1606.83
			2010		
lower Egypt	19.89	1192.06	307.66	3.0	2629.56
middle Egypt	0	1761.26	301.36	2.1	1841.95
New areas	1.61	1827.17	376.03	2.0	1760.82
			2011		
lower Egypt	2.31	1079.25	289.61	3.1	2849.12
middle Egypt	0	1756.38	323.54	2.0	1826.62
New areas	0.24	1754.09	400.38	1.9	1764.71
			2012		
lower Egypt	19.27	1121.80	287.58	3.0	2741.84
middle Egypt	26.09	1410.97	275.21	2.5	2246.83
New areas	0	1746.69	386.22	2.0	1783.00

2- Energetic water productivity (Kcal/m^3)

The average water energetic productivity for Egypt is about 2155.9 Kcal/m^3. Concerning the energetic water productivity per region, Lower Egypt has the highest revenues per one cubic meter of water (about 2747 Kcal/m^3), followed by Middle Egypt (about 2005.4 Kcal/m^3), New Areas have productivities of water less than 1715 Kcal/m^3. The highest water footprint is the lowest energetic water productivity because of this productivity is depending on water footprint. So the highest energetic water productivity region is where preferred planting rice in Lower Egypt.

3- Economic water productivity ($/m^3)

The average water economic productivity for Egypt is about 2.5 $/m^3. As given in Table 3 Lower Egypt has the highest economic water productivity so rice should be planted in it to get high income. As well as, New Areas have the lowest economic water productivity so rice should not be planted in it. High economic productivity means high income from low water footprint.

4- Virtual water trade flows and the national virtual water trade balance

The net virtual water export of a country is equal to the gross virtual water export minus the gross virtual water import. Net virtual water import to a country has either a positive or a negative sign. The latter indicates that there is net virtual water export from the country. In this case, Egypt has net virtual water export 11.64 Tm^3/year. The following figure (2) illustrates the economic water productivity for each year and the energetic water productivity for period (2008-2012).

It is quite clear that imported water economic productivity is lower than the exported water productivity. So Egypt has to stop exporting rice as it is not economic for Egypt. Where the one exported cubic meter is costing more than one imported cubic meter. For calculating the estimated planted area to cover the local consumption, the imported rice trade is about 0.35 Mton/year and the exported rice trade is nearly 2.43 Mton/year. But Egypt produces about 5.88 Mton/year. Therefore the estimated planted area is nearly 0.95 MFed/year; the local consumption is approximately 3.8 Mton/year.

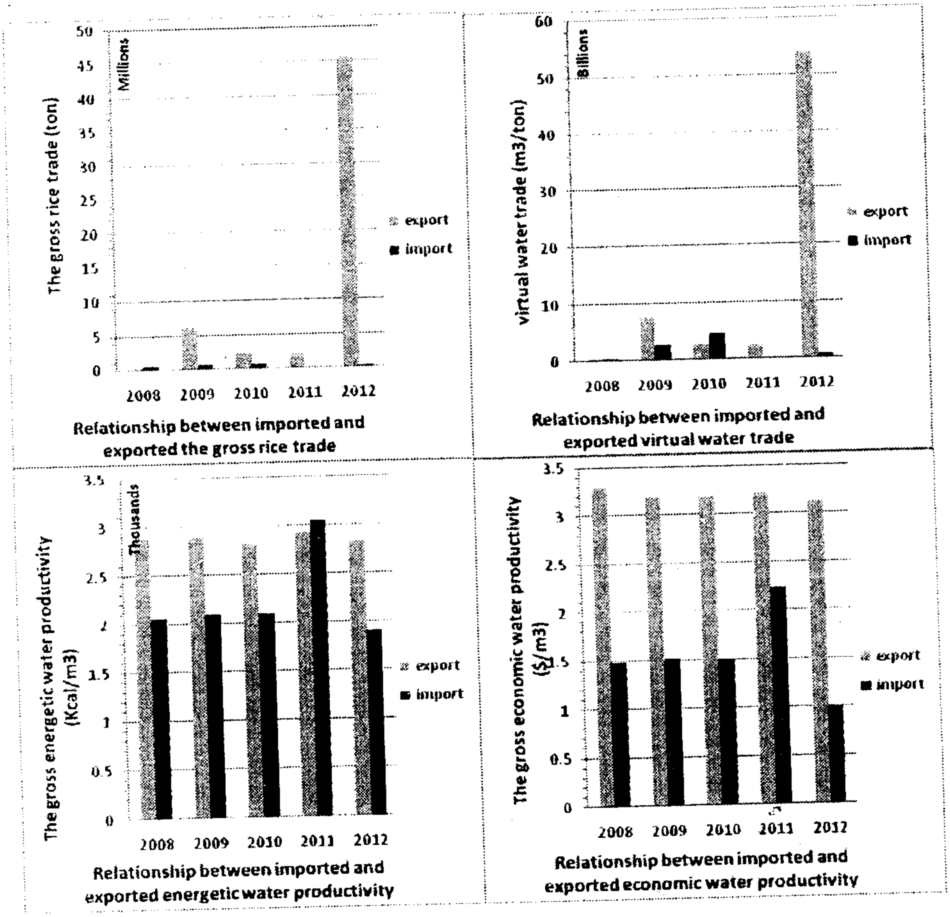

Fig. 2 The national virtual water trades balance of rice over the period 2008-2012.

Wheat crop

1- Cropping area

The total planted area of wheat in Egypt is about 3.4 MFed. As a whole is about 51.5% of the crop area is planted in Lower Egypt. Middle Egypt planted about 25.7% of total planted area. On the other side Upper Egypt planted about 15.8% of total area. There is about 7% of total planted area which planted in New Areas. The total planted area for wheat in (2008-2012) is shown in Table (4).

Table 4: The total planted area of wheat (Feddan) over the period (2008-2012)

Egyptian Region	Years					Average
	2008	2009	2010	2011	2012	
Lower	1620998	1822269	1694940	1737630	1799987	1735165
Middle	535598	566050	548730	2021863	650148	864478
Upper	507792	542049	522898	528623	564673	533207
NewAreas	255996	216660	225813	233485	235852	233561
Total area	2920384	3147028	2992381	4521601	3250660	3366411

2- Total water footprint for wheat

Figure 3 provides an overview of the water footprint of wheat (m^3/ton) in the different regions of Egypt, over different years. As shown in this figure, it is noteworthy that, New Areas containing larger amounts of water footprint (about 3189 m^3/ton), Upper Egypt (about 2076 m^3/ton) and Middle Egypt (about 1708 m^3/ton), however, Lower Egypt containing smaller amounts of water footprint (1511 m^3/ton). This result may be explained by differences in yield, climate, and soil type for each region. The soil type in Lower Egypt is black and salty soil however Middle and Upper Egypt and New Areas are medium black and sandy soil. In Lower Egypt, the wheat yield is about 6.3 ton/ha however the yield in Upper Egypt and New Areas are 6.17 and 5.7 ton/ha respectively.

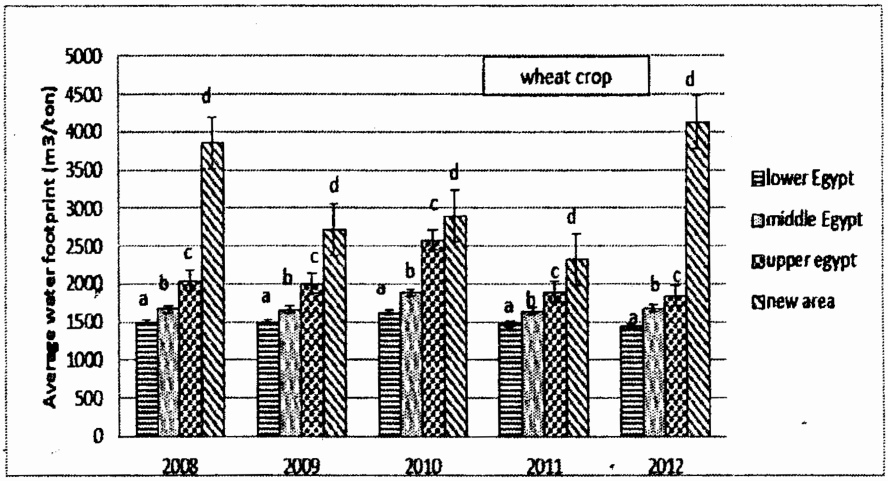

Fig. 3 Total water footprint of wheat over the period 2008-2012

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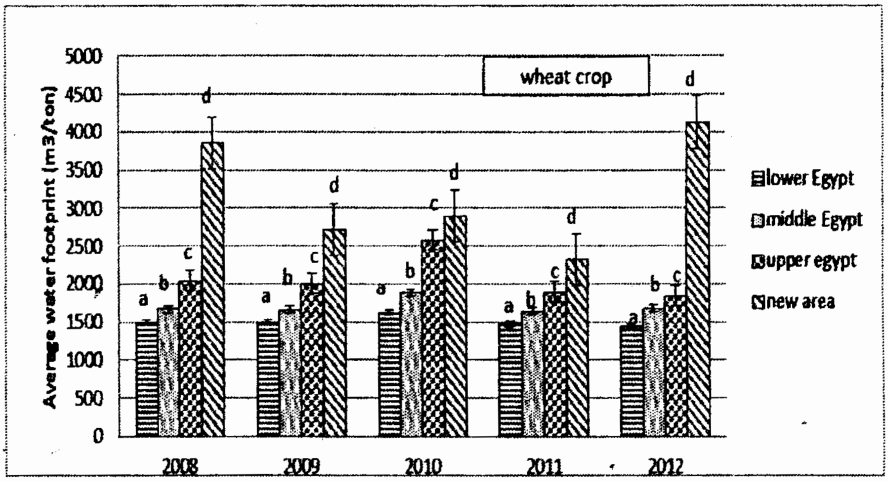

Fig. 3 Total water footprint of wheat over the period 2008-2012

Table 5: Means, Standard Deviation and Duncan's Multiple Range Test for total water footprint of wheat in different regions over the period (2008-2012).

years	Egyptian regions							
	Lower		Middle		Upper		New areas	
	Means	SD	Means	SD	Means	SD	Means	SD
2008	1496 N	152	1670 N	166	2042 N	347	3859 *	2625
2009	1503 N	150	1659 N	102	2004 N	409	2724 *	1075
2010	1628 N	167	1886 N	178	2587 *	458	2904 *	1004
2011	1478 N	187	1642 N	114	1902 N*	279	2328 *	978
2012	1448 N	221	1683 N	45	1848 N	363	4130 *	4229

* and N having the same letter in each column are not significantly at $p_r < 0.05$.

3- Energetic water productivity (Kcal/m^3)

The average water energetic productivity for Egypt is about 1797 Kcal/m^3.Concerning the energetic water productivity per region, Lower Egypt has the highest revenues per one cubic meter of water (about 2224 Kcal/m^3), followed by Middle and Upper Egypt (about 1954 and 1656 Kcal/m^3), New Areas have productivities of water less than 1355 Kcal/m^3). The highest water footprint is the lowest energetic water productivity as the energetic water productivity depends on water footprint.

4- Economic water productivity (\$/m^3)

The average water economic productivity for Egypt is about 1.5 \$/m^3. As given from Table 6 Lower Egypt has the biggest economic water productivity so wheat should be planted in it to get high income. As well as, New Areas have the lowest economic water productivity so wheat should not be planted in New Areas. High economic productivity means that get high income from low water footprint so highest economic productivity region is preferred planting wheat with regard to **Liqiang *et.al.* (2011).**

5- Virtual water flows and the national virtual water trade balance

The net virtual water import of wheat is equal to the gross virtual water import minus the gross virtual water export. Net virtual water import has a positive sign. In this case, Egypt has net virtual water import 512.9 Tm^3/year. The following Figure (4) illustrates the economic water productivity for each year and the energetic water productivity for period (2008-2012).

Table 6: Internal water footprint of produced wheat (m^3/ton) for each region in Egypt over the period (2008-2012).

Region	Water footprint (m3/ton)			Economic water productivity ($\$/m^3$)	Energetic water productivity (Kcal/ m^3)
	Green	Blue	Grey		
2008					
Lower Egypt	14.5	987.4	494	2.34	2235.9
Middle Egypt	6.4	1192.4	471	2.09	1999.4
Upper Egypt	0	1531.6	510	1.74	1658.4
New areas	143	2479.1	1237	1.25	1187.6
2009					
Lower Egypt	10.8	990.9	502	2.33	2223.3
Middle Egypt	0.8	1188.9	470	2.10	2003.6
Upper Egypt	40.2	1449.8	514	1.79	1701.9
New areas	94.9	1848.2	781	1.44	1375.3
2010					
Lower Egypt	25.1	1065.2	538	2.32	2054.5
Middle Egypt	58.2	1302.8	525	2.00	1770.1
Upper Egypt	17.9	1903.9	665	1.48	1311.8
New areas	148.3	1951.5	805	1.41	1244.9
2011					
Lower Egypt	25.1	1065.2	538	2.32	2054.5
Middle Egypt	58.2	1302.8	525	2.00	1770.1
Upper Egypt	17.9	1903.9	665	1.48	1311.8
New areas	148.3	1951.5	805	1.41	1244.9
2012					
Lower Egypt	64.4	904.9	479	2.57	2334.4
Middle Egypt	71.6	1149.2	462	2.17	1970.5
Upper Egypt	96.6	1249.5	501.4	2.22	1838.9
New areas	228	2515.3	1387.2	1.50	1375.4

It is quite clear that, the exported water economic productivity is lower than imported water productivity so Egypt has to stop importing wheat because it is not economic. For calculating the estimated planted area to cover the local consumption, the imported wheat trade was about 420.6 Mton/year. But Egypt produced about 8.3 Mton/year. The local consumption was approximately 428.86 Mton/year where the exported wheat trade was about 0.04 Mton/year. The estimated planted area is nearly 135.2 MFed/year but it is a huge area to be planted wheat and it is not available to plant. So it is suggested to raise wheat yield and increase the planted area as possible.

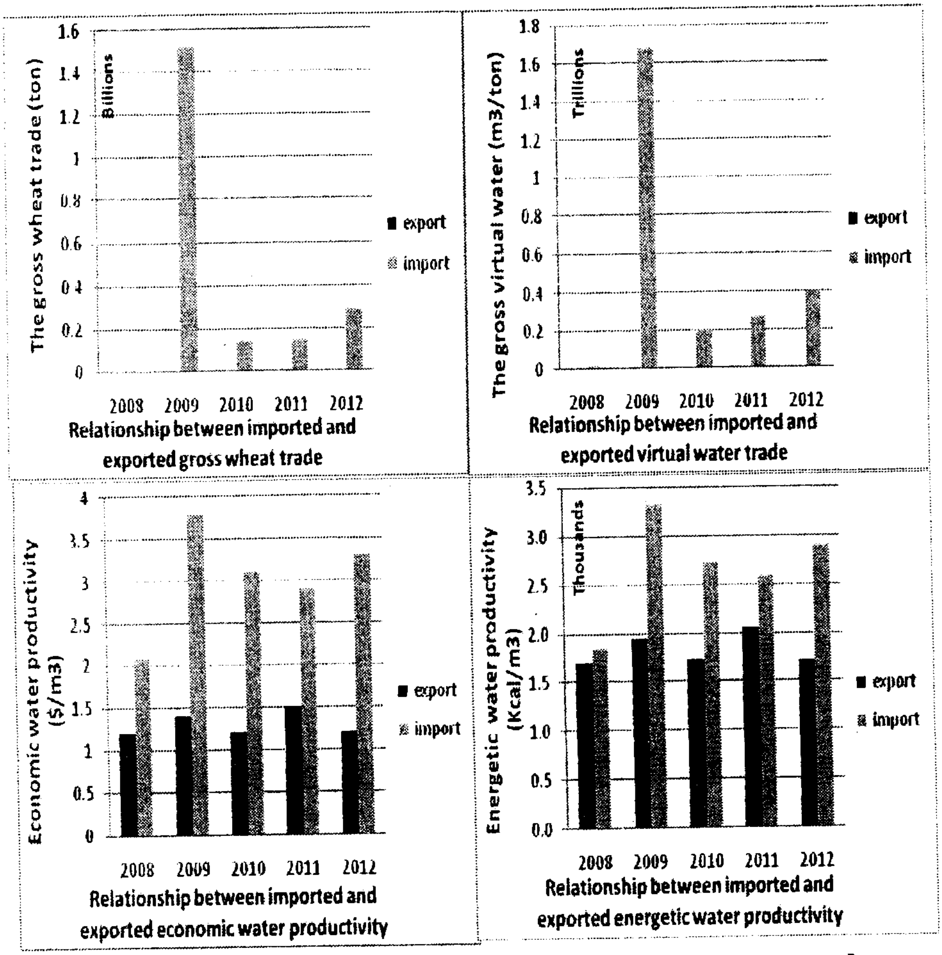

Fig. 4 The national virtual water trades balance of wheat over the period (2008-2012).

Maize crop

1- Cropping area

The total planted area of maize in Egypt is about 1.95 MFed. As a whole 49% of the crop area is planted in Lower Egypt. Middle Egypt planted about 29% of total planted area. On the other side, Upper Egypt planted about 18% of total area. There is about 4% of total planted area which planted in New Areas. The total planted area for maize in (2008-2012) is shown in Table (7).

Table 7: The total planted area of maize (Feddan) over the period (2008-2012).

Egyptian Region	Years					Average
	2008	2009	2010	2011	2012	
Lower	881926	931566	1056405	878027	1053619	960309
Middle	565582	619727	541503	496466	634209	571497
Upper	344516	347080	338343	314917	379866	344944
New	68339	79198	61997	69152	89382	73614
Total	1860363	1977571	1998248	1758562	2157076	1950364

2- Total water footprint for maize

Figure (5) provides an overview of the water footprint of maize (m^3/ton) in the different regions of Egypt over different years. As shown in this figure, it is noteworthy that, New Areas containing larger amounts of water footprint (about 3464 m^3/ton), Upper Egypt (about 2486 m^3/ton) and Middle Egypt (about 1822 m^3/ton), however, Lower Egypt containing smaller amounts of water footprint (about 1601.6 m^3/ton). This result may be explained by differences in yield, climate, and soil type for each region. In Lower Egypt, maize yield is about 8.2 ton/ha however yield in Upper Egypt and New Areas are about 6.1 and 5.7 ton/ha. As clear from results that, Lower Egypt quite has the lowest water footprint so it preferred planting maize.

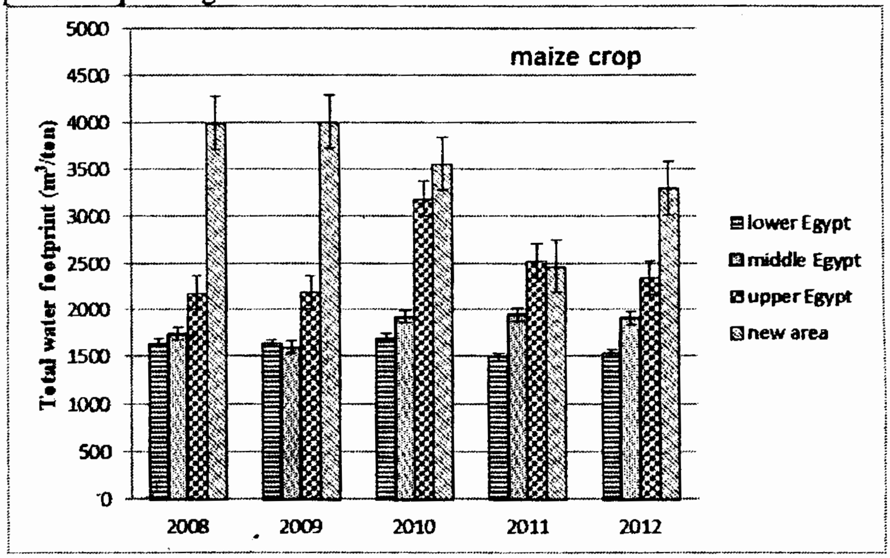

Fig.5 Total water footprint of Maize over the period 2008-2012

3- Energetic water productivity (Kcal/m^3)

The average water energetic productivity for Egypt is about 2263 Kcal/m^3. Concerning the energetic water productivity per region, Lower Egypt has the highest revenues per one cubic meter of water (2956 Kcal/m^3), followed by Middle and Upper Egypt (about 2435 and 1825 Kcal/m^3), New Areas have productivities of water less than 1833 Kcal/m^3). The highest water footprint is the lowest energetic water productivity as the energetic water productivity depends on water footprint.

Table 8: Means, Standard Deviation and Duncan's Multiple Range Test for total water footprint of maize in different regions over the period (2008-2012)

years	Egyptian regions							
	Lower		Middle		Upper		New areas	
	Means	SD	Means	SD	Means	SD	Means	SD
2008	1643 ^{N}	332	1736^N	295	2182^N	536	3997*	2738
2009	1640 ^{N}	398	1599^N	278	2189^N	581	4006*	3167
2010	1700 ^{N}	507	1929^N	480	3181^{N*}	646	2559*	3101
2011	1492 ^{N}	226	1943^{N*}	300	2531*	672	2469*	978
2012	1533 ^{N}	281	1905^N	252	2532^{N*}	530	3293*	2590

* and N having the same letter in each column are not significantly at $p_r < 0.05$.

4- Economic water productivity ($/m^3)

The average water economic productivity for Egypt is about 2 $/m^3. High economic productivity means that get high income from low water footprint. As given from Table 9 the Lower Egypt has the highest economic water productivity so maize should be planted in it to get high income. As well as, New Areas have the lowest economic water productivity so maize has not to be planted in New Areas.

5- Virtual water flows and the national virtual water trade balance

The net virtual water import of maize is equal to the gross virtual water import minus the gross virtual water export. Net virtual water import has a positive sign. In this case, Egypt has net virtual water import 106.8 Tm^3/year. The following Figure (6) illustrates the economic water productivity for each year and the energetic water productivity for period (2008-2012).

Table 9: Internal water footprint of maize produced (m^3/ton) for each region in Egypt over the period (2008-2012)

Region	Water footprint (m^3/ton)				Economic water productivity ($/ m^3)	Energetic water productivity (Kcal/ m^3)
	Green	Blue	Grey	Total		
			2008			
lower Egypt	24.3	933.4	685.5	1643.2	2.3	2794.9
middleEgypt	22.5	1073.0	640.0	1735.6	2.2	2541.9
Upper Egypt	30.6	1411.6	739.6	2181.8	1.8	2025.9
New areas	40.8	2306.6	1650.0	3997.5	1.3	1586.7
			2009			
lower Egypt	16.3	937.6	686.9	1640.8	2.44	2817.7
middleEgypt	6.2	988.3	604.7	1599.2	2.5	2777.6
Upper Egypt	17.0	1423.6	748.1	2188.8	1.9	2038.9
New areas	11.8	2363.7	1630.8	4006.3	1.5	1711.6
			2010			
lower Egypt	45.4	955.2	699.0	1699.6	2.47	2765.2
middleEgypt	54.8	1197.9	676.4	1929.1	2.24	2330.5
Upper Egypt	17.4	2135.7	1027.8	3181.0	1.4	1359.5
New areas	7.9	2043.4	1507.2	3558.5	1.7	1880.7
			2011			
lower Egypt	7.2	856.9	627.8	1491.9	2.6	3171.6
middleEgypt	13.4	1234.3	696.2	1943.9	2.02	2245.6
Upper Egypt	11.0	1659.8	860.8	2531.6	1.6	1746.4
New areas	24.7	1458.6	985.9	2469.2	1.8	2053.0
			2012			
lower Egypt	35.6	863.6	633.7	1532.9	2.58	3231.5
middleEgypt	44.5	1167.9	692.4	1904.9	2.05	2279.1
Upper Egypt	16.1	1503.7	827.1	2346.9	1.71	1956.7
New areas	10.9	1894.6	1387.2	3292.6	1.69	1936.9

It is quite clear that the exported water economic productivity is lower than imported water productivity. So Egypt has to stop importing maize because it is not economic. For calculating the estimated planted area to cover the local consumption, the imported maize trade is about 114.9 Mton/year. But Egypt produces about 6.5 Mton/year. The local consumption is approximately 121.16 Mton/year where exported maize trade is about 0.015 Mton/year. The estimated planted area is nearly 36.7 MFed/year but it is a huge area to be planted maize and it is not available to plant. So it is suggested to raise maize yield and increase the planted area as possible.

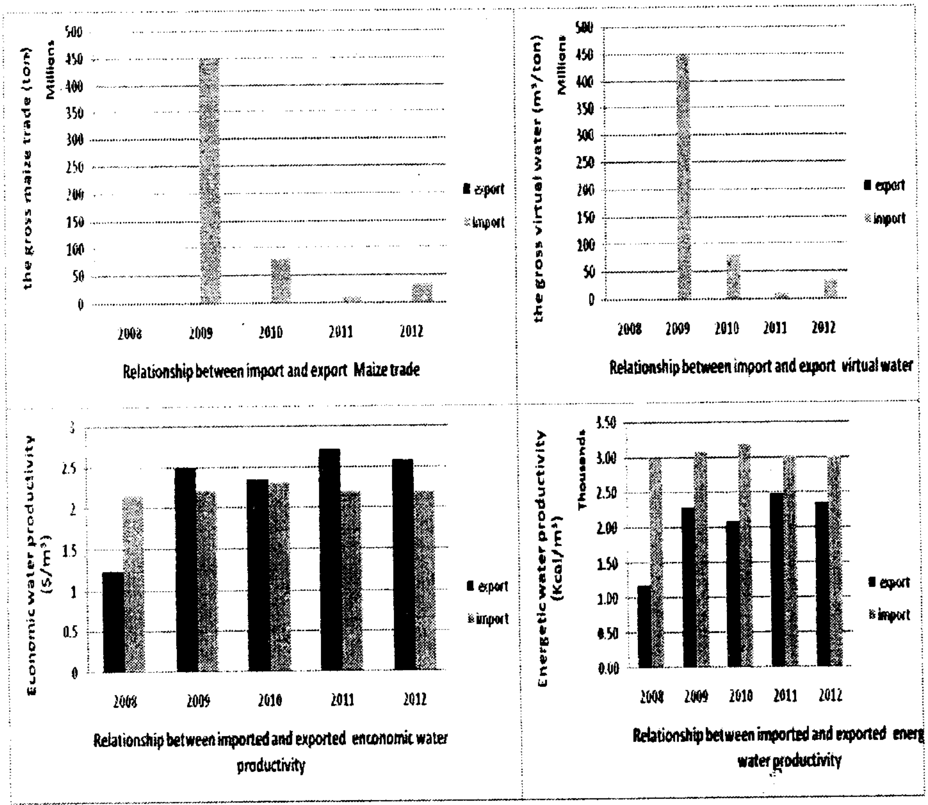

Fig. 6 The national virtual water trades balance of maize over the period (2008-2012).

Sugarcane crop

1- Cropping area

The total planted area of sugarcane in Egypt is about 322879 Fed. As a whole 1.13% of the crop area is planted in Lower Egypt. Middle Egypt planted about 13% of total planted area. On the other side Upper Egypt planted about 85.8% of total area. There is about 0.096% of total planted area which planted in new areas. The total planted area for sugarcane in (2008-2012) is shown in Table (10).

2- Total water footprint for sugarcane

Figure (7) provides an overview of the water footprint of sugarcane (m^3/ton) for the different regions in Egypt over different years. As shown in this figure, it is noteworthy that, New Areas containing larger amounts of water footprint (about 1101.52 m^3/ton), Middle Egypt (about 368

m^3/ton) and, Lower Egypt (about 300 m^3/ton) however, Upper Egypt containing smaller amounts of water footprint (about 288 m^3/ton). This result may be explained by the differences in yield, climate, and soil type for each region, there are different in water footprint. In Upper Egypt, sugarcane yield is about 106.5 ton/ha however yield in Middle Egypt and New Areas are 82 and 23.5 ton/ha. As clear from results that, Upper Egypt has the lowest water footprint so sugarcane is preferred to planted in Upper Egypt.

Table 10: The total planted area of Sugarcane (Fadden) over the period (2008-2012)

Egyptian Region	Years					Average
	2008	2009	2010	2011	2012	
Lower	2521	3087	3264	3515	5853	3648
Middle	41467	40906	42245	42487	42155	41852
Upper	279246	272560	274485	279068	279984	277069
New Areas	356	159	159	428	450	310
Total area	323590	316712	320153	325498	328442	322879

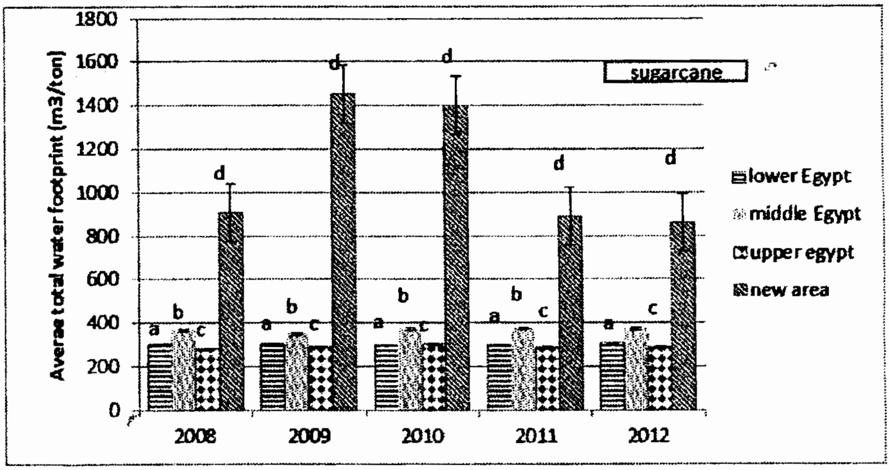

Fig. 7 Total water footprint of Sugarcane over the period 2008-2012

3- **Energetic water productivity (Kcal/m^3)**

The average water energetic productivity for Egypt is about 1031.4 Kcal/m^3. Concerning the energetic water productivity per region, Upper Egypt has the highest revenues per one cubic meter of water (1367

Kcal/m^3), followed by Lower and Middle Egypt (about 1312 and 1082Kcal/m^3), New Areas have productivities of water less than 364 Kcal/m^3). The highest water footprint is the lowest energetic water productivity because of the energetic water productivity depends on water footprint.

Table 11: Means, Standard Deviation and Duncan's Multiple Range Test for total water footprint of sugarcane in different regions over the period (2008-2012).

Years	Egyptian regions							
	Lower		Middle		Upper		New areas	
	Means	SD	Means	SD	Means	SD	Means	SD
2008	300^{N}	55	366^{N}	80	277^{N}	51	906^{*}	-
2009	310^{N}	52	346^{N}	78	289^{N}	59	1451^{*}	-
2010	305^{N}	61	371^{N}	100	302^{N}	63	1399^{*}	-
2011	297^{N}	62	375^{N}	102	286^{N}	59	890^{*}	-
2012	306^{N}	71	373^{N}	111	288^{N}	75	862^{*}	-

* and N having the same letter in each column are not significantly at $p_r < 0.05$.

4- **Economic water productivity (\$/m^3)**

The average water economic productivity for Egypt is about 1.36 \$/m^3. High economic productivity means that get high income from low water footprint. As given from Table (12) the Upper Egypt has the highest economic water productivity so sugarcane should be planted in it to get high income. As well as, New Areas have the lowest economic water productivity so sugarcane has not to be planted in New Areas.

5- **Virtual water flows and the national virtual water trade balance**

The net virtual water import of sugar is equal to the gross virtual water import minus the gross virtual water export. Net virtual water import has a positive sign. In this case, Egypt has net virtual water import 132.9 Mm^3/year. The following Figure (8) illustrates the economic water productivity for each year and the energetic water productivity for period (2008-2012).

Table 12: Internal water footprint of sugar cane produced (m^3/ton) for each region in Egypt over the period (2008-2012)

Region	Water footprint (m^3/ton)				Economic water productivity ($/ m^3)	Energetic water productivity (Kcal/ m^3)
	Green	Blue	Grey	Total		
2008						
lower Egypt	2.4	266.6	30.7	299.7	1.40	1309.4
middleEgypt	2.7	332.1	31.4	366.2	1.12	1080.1
Upper Egypt	0.3	256.4	20.8	277.4	1.50	1406.1
New areas	0	807.4	99.0	906.4	0.44	418.9
2009						
lower Egypt	4.3	268.4	30.8	303.5	1.41	1285.1
middleEgypt	-3.7	323.8	30.3	350.4	1.23	1120.4
Upper Egypt	17.7	249.3	21.8	288.8	1.50	1359.1
New areas	0	1294.5	156.0	1450.5	0.29	261.8
2010						
lower Egypt	2.4	265.1	30.0	297.5	1.49	1321.7
middleEgypt	5.2	337.6	30.2	372.9	1.20	1064.7
Upper Egypt	1. 6	278.6	21.6	301.8	1.47	1303.8
New areas	0	1243.3	156.0	1399.3	0.31	271.4
2011						
lower Egypt	7.5	258.7	30.8	296.9	1.51	1335.1
middleEgypt	3.5	341.2	30.8	375.4	1.16	1070.6
Upper Egypt	0.4	264.0	21.8	286.2	1.51	1376.9
New areas	0	785.7	103.9	889.6	0.47	426.9
2012						
lower Egypt	6.3	269.1	30.9	306.3	1.48	1307.3
middleEgypt	3.7	338.9	30.8	373.4	1.15	1075.9
Upper Egypt	0.4	264.2	23.0	287.6	1.53	1391.3
New areas	27.6	732.9	101.3	861.7	0.48	440.7

It is quite clear that the exported water economic productivity is lower than imported water productivity. So Egypt has to stop exporting sugarcane because it is not economic. For calculating the estimated planted area to cover the local consumption, the imported and exported sugarcane trades are about 2.4 and 0.19 Mton/year. But Egypt produces about 15 Mton/year. Therefore the estimated planted area is nearly 369484.92 Fed/year; the local consumption was approximately 17.14 Mton/year.

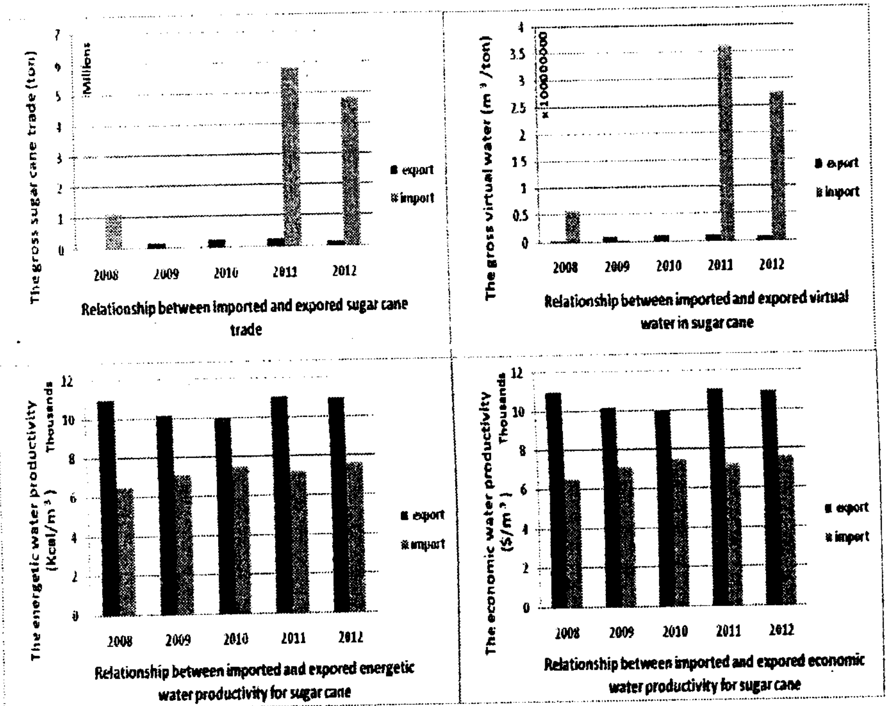

Fig. 8 The national virtual water trades balance of sugarcane over the period (2008-2012).

CONCLUSIONS

The analyses of water footprint and virtual water trade provide very interesting results as follows:

a) Rice crop

As seen from results that Lower Egypt has the lowest water footprint (1435.9m^3/ton) and highest economic productivity (3 \$/m^3). So it is recommened to cultivate rice in Lower Egypt. There are two words should be stated in the section related to the virtual water flow balances for rice, stop exporting rice. The one cubic meter of water used in rice production in Egypt costs 3\$, but the imported one cubic water in rice costs about 1.5\$. So it is suggested to cultivate about 937016 Fed rice in Lower Egypt to cover the national consumption.

b) Wheat crop

It is quite clear that Lower Egypt has the lowest water footprint (1511 m^3/ton) and highest economic productivity (1.95 \$/m^3). So Lower Egypt is the place where Egypt has to plant wheat. In the section related to the virtual water flow balances for rice, The one cubic meter of water used in wheat production costs 1.8$, but the imported one cubic water of rice getting income about 3$. In Egypt, there are a huge deficit between the production and national consumption. To cover this deficit, Egypt has to plant about 135.2 MFed of wheat per year. But it is a huge area and this area not available. So it is important to raise wheat yield and increase planted area as possible.

c) Maize crop

Lower Egypt has the lowest water footprint (1602 m^3/ton) and highest economic productivity (2.5 $/$m^3$). So Lower Egypt is the place where Egypt has to plant maize. It is quite clear that annual Egypt maize consumption is about 121.2 Mton/year. The one cubic meter of water used in maize production in Egypt costs 2$, but the imported one cubic water of maize costs about 3$. Egypt has to stop importing maize. So Egypt has to plant about 36.7 MFed/year to cover nation consumption but it is a huge area and this area not available. So it is important to raise maize yield and increase planted area as possible.

d) Sugarcane crop

As seen from results that Upper Egypt has the lowest water footprint (288 m^3/ton) and highest economic productivity (1.44 $/$m^3$). So it is important to cultivate sugarcane in Upper Egypt. There are two words should be stated in the section related to the virtual water flow balances for sugarcane, stop exporting sugar. The one cubic meter of water using in sugarcane production in Egypt costs 10$, but the imported one cubic water in rice costs about 7$. So it is suggested to cultivate about 3694984.9 Fed sugarcane to cover national consumption.

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الملخص العربى

دراسة عن المياه العابرة للحدود والبصمة المائية لبعض المحاصيل فى مصر

م/ أسماء على خليل[1] د/ محمد ماهر ابراهيم[2] أ.د/ محمود هانى رمضان[3]

عن طريق الربط بين مجموعة من المؤشرات والقضايا وجد أن تحليل البصمة المائية والمياه الإفتراضية للمحاصيل المختلفة يقدم ورقة عمل مناسبة بها مجموعة من الحلول لعمل إدارة متكاملة للمياه. حيث أن مفهوم المياه العابرة للحدود والبصمة المائية يساعد على تحسين استراتيجيات الدول الزراعية وبنية التجارة الدولية وتحسين معدل إستهلاك الأمم بما يتوافق.مع مصادر المياه المتاحة.

ولهذا تم إجراء تحليل للبصمة المائية والمياه الإفتراضية لمجموعه من المحاصيل وهى الأرز والقمح والذرة الشامية وقصب السكر وذلك خلال الفترة من ٢٠٠٨ الى ٢٠١٢. وقد تبين نتيجة لهذا التحليل الأتى:

أنه بالنسبة لمحصول الأرز فإن أفضل منطقة لزراعته هى مصر السفلى وذلك حيث أنها تحتوى على أقل بصمة مائية للمحصول (١٤٣٥,٩ م^{٣}/طن) وأعلى إنتاجية إقتصادية للمياه (٣ دولار / م^{٣} ماء). وقد وجد أن سعر المتر المكعب المستخدم فى إنتاج محصول الأرز داخل مصر يعادل ٣ دولار/ م^{٣} بينما سعر المتر مكعب ماء للأرز الذى يتم إستيراده يعادل ١,٥ دولار/ م^{٣}. ومما سبق فإنه من غير الإقتصادى تصدير الأرز لذلك ينصح بزراعة ما يعادل ٩٣٧٠١٦ فدان أرز سنويا لتغطية الإستهلاك المحلى وهذا سيوفر ما يقرب من ١٧٣,٩٦ مليون متر مكعب ماء سنويا.

بالنسبة لمحصول القمح فإنه يوجد فجوة كبيرة بين الإستهلاك والإنتاج فى مصر ولذلك يجب تغطية الإستهلاك المحلى حيث أنه من غير الإقتصادى إستيراد القمح لذلك ينصح بزراعة حوالى ١٣٥,٢ مليون فدان وإذا كانت هذه المساحة كبيرة جدا للزراعة فيجب العمل على زراعة أصناف ذات إنتاجية عالية. ويفضل زراعته داخل مصر السفلى والوسطى لوجود أقل بصمة مائية له وأعلى إنتاجية إقتصادية للمياه.

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بينما نتائج محصول الذرة الشامية فقد أتضح أن أفضل منطقة لزراعته هى مصر السفلى وذلك لتقارب نتائج البصمة المائية لزراعة الذرة الشاميه هناك (١٦٠١,٦ م^{٣}/طن). وقد وجد أنه يجب إيقاف إستيراد الذرة وتغطية الإستهلاك المحلى فقط حيث أن سعر المتر المكعب المستخدم فى إنتاج محصول الذرة داخل مصر يعادل ٢ دولار/ م^{٣} بينما سعر المتر مكعب ماء للذرة الذى يتم إستيراده يعادل ٣ دولار/ م^{٣}. ومما سبق فإنه من غير الإقتصادى إستيراد الذرة. ولتغطية الإستهلاك المحلى يجب زراعة مايعادل ٣٦,٧ مليون فدان سنويا. ولكن هذه المساحه غير متوفرة فى مصر لذلك يجب رفع إنتاجية محصول الذرة وزيادة المساحة المزروعة قدر المستطاع لتغطية الإستهلاك المحلى.

و قصب السكر يعطى أقل بصمة مائية له فى مصر العليا (٢٨٨م^{٣}/طن) وأعلى إنتاجية إقتصادية للمياه ١,٤٤ دولار لكل م^{٣} ماء. لذلك ينصح بزراعته فى مصر العليا. ومن النتائج المتحصل عليها وجد أنه من غير الأقتصادى إستيراد السكر لذلك فإنه ينصح بزراعة ٢,٢٥ مليون فدان سنويا لتغطية الإستهلاك المحلى.